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BASIC HUMAN PHYSIOLOGY: NORMAL FUNCTION AND MECHANISMS OF DISEASE

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Dedicated to
the modern student,
often a quixotic being,
but far brighter than his forebears
despite what his forebears often think

PREFACE

I have written this book for those students who wish more than an elementary introduction to the physiology of the human body and yet who cannot afford the time or perhaps might not have the background to study one of the more formidable textbooks. A special attempt has been made to give wide coverage to all aspects of human physiology but still to present the material at a level that is acceptable to the previous training of essentially all college and early professional students. And throughout the text I have attempted to present bodily mechanisms in the light of well known physical and chemical laws, not merely to describe physiological function as if it were unrelated to other scientific disciplines.

I have also given a strong "human" flavor to the book. Many textbooks of human physiology are in reality animal physiology placed in a human setting. Obviously, a major share of the information used to develop the present book also came from basic experiments in animals. Yet, another large body of knowledge has come from human experimentation, both planned experiments in normal human beings and unplanned experiments caused by disease. Indeed, one of the reasons for discussing the physiology of some diseases in this text has been to give it its human flavor. For instance, when one discusses the regulation of blood glucose or of carbohydrate metabolism or of fat metabolism, it is almost ridiculous not to discuss simultaneously the basic physiology of diabetes mellitus, a disease that affects all these physiological functions and that is widespread among the human population, one that affords a constant example of a ubiquitous and important physiological experiment. By the same token, literally thousands of human "experiments" proceed each day in the fields of high blood pressure, congestive heart failure, gastrointestinal disturbances, respiratory diseases, and so forth. The physiology of these abnormalities should be the property of every student of human physiology rather than being reserved in a special niche for only the medical student or physician.

I hope that I can leave the student with the knowledge that the human body is one of the most complex and yet most beautiful of all functional mechanisms. Think for a moment that the human brain carries within it a computer with capabilities and functions that all the electronic computers of the world put together cannot at present achieve. Think of the individual living cell, the basic structural component of the body, that has within it all the genetic components of the entire human being, in reality a myriad of control systems for literally thousands of chemical reactions

within each cell. I could go on detailing the miracles of the human body. That, indeed, is the purpose of this entire text. The success that I have in exciting the student to further study in the field of physiology or to a lifetime of physiological thinking will determine whether or not I have been successful in my own goal in writing this text.

A vast amount of actual labor always goes into the development and publication of a text. For the majority of the figures in the text I am especially indebted to Mrs. Carolyn Hull, and for the great quantity and quality of secretarial services I owe my gratitude to Mrs. Billie Howard and Mrs. Judy Bass. Finally, I extend my appreciation to the staff of the W. B. Saunders Company for its continued excellence in all publication matters, particularly for the novel and, to me at least, enticing format that has been achieved.

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PART I

THE CELL AND GENERAL PHYSIOLOGY

PART I

CHAPTER 1

FUNCTIONAL ORGANIZATION OF THE HUMAN BODY AND CONTROL OF THE "INTERNAL ENVIRONMENT"

In human physiology we attempt to explain such effects as the chemical reactions in the cells, the transmission of nerve impulses from one part of the body to another, contraction of the muscles, reproduction, and even the minute details of transformation of light energy into chemical energy to excite the eyes, thus allowing us to see the world. The very fact that we are alive is almost beyond our own control, for hunger makes us seek food and fear makes us seek refuge. Sensations of cold make us provide warmth, and other forces cause us to seek fellowship and reproduce. Thus, the human being is actually an automaton, and the fact that we are sensing, feeling, and knowledgeable beings is part of this automatic sequence of life; these special attributes allow us to exist under widely varying conditions, which otherwise would make life impossible.

Cells as the Basic Living Units of the Body. The basic living unit of the body is the cell, and each organ is actually an aggregate of many different cells held together by intercellular supporting structures. Each type of cell is specially adapted to perform one particular function. For instance, the red blood cells, twenty-five trillion in all, transport oxygen from the lungs to the tissues. Though this type of cell is perhaps the most abundant of any in the whole body, there are approximately another 75 trillion cells. The entire body, then, contains about 100 trillion cells.

Cells are automatons that are capable of living, growing, and providing their special functions so long as the proper concentrations of oxygen, glucose, the different electrolytes, amino acids, and fatty substances are available in the tissue fluids of the body.

Almost all cells also have the ability to reproduce, and whenever cells of a particular type are destroyed for one cause or another, the remaining cells of this type usually divide again and again until the appropriate number is replenished.

THE EXTRACELLULAR FLUID — THE INTERNAL ENVIRONMENT

About 56 per cent of the adult human body is fluid. Some of this fluid is inside the cells and is called, collectively, the *intracellular fluid.* The fluid in the spaces outside the cells is called the *extracellular fluid.* Among the dissolved constituents of the extracellular fluids are the ions and the nutrients needed by the cells for maintenance of life. The extracellular fluid is in constant motion throughout the body and is constantly mixed by the blood circulation and by diffusion between the blood and the tissue spaces. Therefore, all cells live in essentially the same environment, for which reason the extracellular fluid is often called the *internal environment* of the body.

Differences Between Extracellular and Intracellular Fluids. The extracellular fluid contains large amounts of sodium, chloride, and bicarbonate ions, plus nutrients for the cells, such as oxygen, glucose, fatty acids, and amino acids. It also contains carbon dioxide, which is being transported from the cells to the lungs, and other cellular excretory products, which are being transported to the kidneys.

The intracellular fluid is much the same from one cell to another, but it differs significantly from the extracellular fluid; particularly, the intracellular fluid contains large amounts of potassium, magnesium, and phosphate ions instead of the sodium and chloride ions found in the extracellular fluid. Special mechanisms for transporting ions through the cell membranes maintain these differences. These mechanisms will be discussed in detail in Chapter 4.

HOMEOSTASIS

The term *homeostasis* is used by physiologists to mean *maintenance of static,* or *constant, conditions in the internal environment.* Essentially all the organs and tissues of the body perform functions that help to maintain these constant conditions. For instance, the lungs provide new oxygen as it is required by the cells, the kidneys maintain constant electrolyte concentrations, and the gut provides nutrients. A large segment of this text is concerned with the manner in which each organ or tissue contributes to homeostasis. To begin this discussion, the different functional systems of the body and their homeostatic mechanisms will be outlined briefly; then the basic theory of the control systems that cause the functional systems to operate in harmony with each other will be discussed.

THE FLUID TRANSPORT SYSTEM

Extracellular fluid is transported to all parts of the body in two different stages. The first stage entails movement of blood around and around the circulatory system, and the second, movement of fluid between the blood capillaries and the cells. Figure 1–1 illustrates the overall circulation of blood, showing that the heart is actually two separate pumps, one of which propels blood through the lungs and the other through the systemic circulation. All the blood in the circulation traverses the entire circuit of the circulation an average of once each minute when a person is at rest and as many as five times each minute when he becomes extremely active.

As blood passes through the capillaries, continual exchange occurs between the plasma portion of the blood and the interstitial fluid in the spaces surrounding the capillaries. This process is illustrated in Figure 1–2. Note that the capillaries are porous so that large amounts of fluid can *diffuse* back and forth between the blood and the tissue

spaces, as illustrated by the arrows. This process of diffusion is caused by kinetic motion of the molecules in both the plasma and the extracellular fluid. That is, all fluid and dissolved molecules are continually moving and bouncing in all directions, through the pores, through the tissue spaces, and so forth. Almost no cell is located more than 25 to 50 microns from a capillary, which allows movement of any substance from the capillary to the cell within a few seconds. Thus, the extracellular fluid throughout the body is continually mixed and thereby maintains almost complete homogeneity.

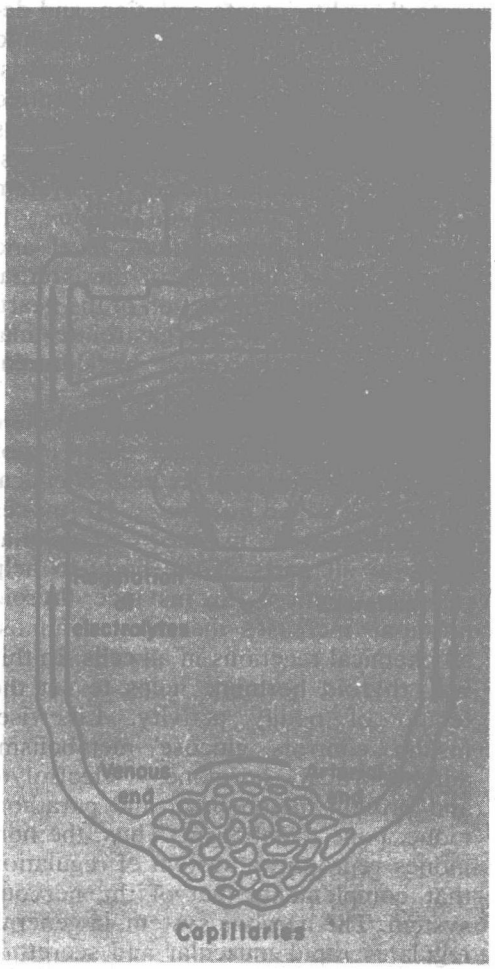

FIGURE 1–1 General organization of the circulatory system.

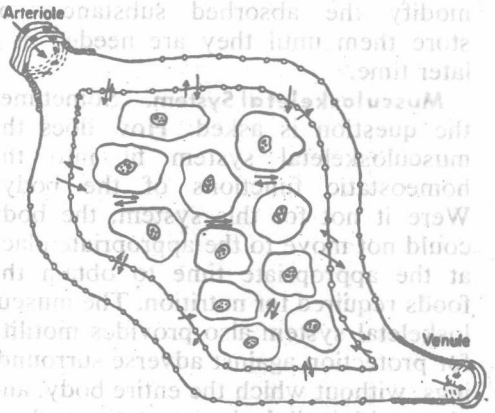

FIGURE 1–2 Diffusion of fluids through the capillary walls and through the interstitial spaces.

ORIGIN OF NUTRIENTS IN THE EXTRACELLULAR FLUID

The Respiratory System. Figure 1–1 shows that each time the blood passes through the body it also flows through the lungs. The blood picks up oxygen in the alveoli, thus acquiring the oxygen needed by the cells. The membrane between the alveoli and the lumen of the pulmonary capillaries is only 1 to 4 microns in thickness, and oxygen diffuses through this membrane into the blood in exactly the same manner that water, nutrients, and excreta diffuse through the tissue capillaries.

The Gastrointestinal Tract. Figure 1–1 also shows that a large portion of the blood pumped by the heart passes through the walls of the gastrointestinal organs. Here, different dissolved nutrients, including carbohydrates, fatty acids, amino acids, and others, are absorbed into the extracellular fluid.

The Liver and Other Organs that Perform Primarily Metabolic Functions. Not all substances absorbed from the gastrointestinal tract can be used in their absorbed form by the cells. The liver alters the chemical compositions of many of these to more usable forms, and other tissues of the body—such as the fat cells, the gastrointestinal mucosa, the kidneys, and the endocrine glands—help to

modify the absorbed substances or store them until they are needed at a later time.

Musculoskeletal System. Sometimes the question is asked: How does the musculoskeletal system fit into the homeostatic functions of the body? Were it not for this system, the body could not move to the appropriate place at the appropriate time to obtain the foods required for nutrition. The musculoskeletal system also provides motility for protection against adverse surroundings, without which the entire body, and along with it all the homeostatic mechanisms, could be destroyed instantaneously.

REMOVAL OF METABOLIC END-PRODUCTS

Removal of Carbon Dioxide by the Lungs. At the same time that blood picks up oxygen in the lungs, carbon dioxide is released from the blood into the alveoli, and the respiratory movement of air into and out of the alveoli carries the carbon dioxide to the atmosphere. Carbon dioxide is the most abundant of all the end-products of metabolism.

The Kidneys. Passage of the blood through the kidneys removes most substances from the plasma that are not needed by the cells. These substances include especially different end-products of metabolism and excesses of electrolytes or water that might have accumulated in the extracellular fluids. The kidneys perform their function by, first, filtering large quantities of plasma through the glomeruli into the tubules and then reabsorbing into the blood those substances needed by the body, such as glucose, amino acids, large amounts of water, and many of the electrolytes. However, substances not needed by the body generally are not reabsorbed but, instead, pass on through the renal tubules into the urine.

REGULATION OF BODY FUNCTIONS

The Nervous System. The nervous system is composed of three major parts: the *sensory portion*, the *central nervous system*, or *integrative portion*, and the *motor portion*. Sensory nerves detect the state of the body or the state of the surroundings. For instance, nerves present everywhere in the skin apprise one every time an object touches him at any point. The eyes are sensory organs that give one a visual image of the surrounding area. The ears also are sensory organs. The central nervous system is comprised of the brain and spinal cord. The brain can store information, generate thoughts, create ambition, and determine reactions that the body should perform in response to the sensations. Appropriate signals are then transmitted through the motor portion of the nervous system to carry out the person's desires.

A large segment of the nervous system is called the *autonomic system*. It operates at a subconscious level and controls many functions of the internal organs, including the action of the heart, the movements of the gastrointestinal tract, and the secretion by different glands.

The Hormonal System of Regulation. Located in the body are eight major endocrine glands that secrete chemical substances called *hormones*. Hormones are transported in the extracellular fluids to all parts of the body to help regulate function. For instance, thyroid hormone increases the rates of almost all chemical reactions in all cells. In this way thyroid hormone helps to set the tempo of bodily activity. Likewise, insulin controls glucose metabolism; adrenocortical hormones, electrolyte and protein metabolism; and parathormone, bone metabolism. Thus, the hormones represent a system of regulation that complements that of the nervous system. The nervous system, in general, regulates rapid muscular and secretory activities of the body, whereas the hor-